Total Maximum Daily Load
For Algae and Turbidity
Silver Lake
Worth County, Iowa

2006

Iowa Department of Natural Resources
Watershed Improvement Section

Table of Contents

1. Executive Summary

Table 1. Silver Lake Summary

Waterbody Name:	Silver Lake
County:	Worth
Use Designation Class:	A1 (primary contact recreation) B(LW) (aquatic life) HQR (high quality resource)
Major River Basin:	Cedar River Basin
Pollutants:	Phosphorus
Pollutant Sources:	Nonpoint external, atmospheric (background), and nonpoint internal (sediment re-suspension and nutrient recycling)
Impaired Use(s):	A1 (primary contact recreation)
2002 303d Priority:	Medium
Watershed Area:	1,708 acres
Lake Area:	334 acres
Lake Volume:	1497 acre-ft
Detention Time:	1.24 years
TSI Target(s):	Total Phosphorus less than 70; Chlorophyll a less than 65; Secchi Depth less than 65
Target Total Phosphorus Load:	See Table 2
Existing Total Phosphorus Load:	1,664 pounds per year
Load Reduction to Achieve Target:	See Table 2
Wasteload Allocation	0
Load Allocation	See Table 2

The Federal Clean Water Act requires the Iowa Department of Natural Resources (IDNR) to develop a total maximum daily load (TMDL) for waters that have been identified on the state's 303(d) list as impaired by a pollutant. Silver Lake has been identified as impaired by algae and turbidity. The purpose of these TMDLs for Silver Lake is to calculate the maximum allowable nutrient loading for the lake associated with algae and turbidity levels that will meet water quality standards.

This document consists of TMDLs for algae and turbidity designed to provide Silver Lake water quality that fully supports its designated uses. Phosphorus, which is related through the Trophic State Index (TSI) to chlorophyll and Secchi depth, is targeted to address the algae and turbidity impairments.

Phasing TMDLs is an iterative approach to managing water quality that becomes necessary when the origin, nature and sources of water quality impairments are not well understood. In Phase 1, the waterbody load capacity, existing pollutant load in excess of this capacity, and the source load allocations are estimated based on the limited information available. A monitoring plan will be used to determine if prescribed load reductions result in attainment of water quality standards and whether or not the target values are sufficient to meet designated uses. Monitoring activities may include routine sampling and analysis, biological assessment, fisheries studies, and watershed and/or waterbody modeling.

Section 5.0 of this TMDL includes a description of planned monitoring. The TMDL will have two phases. Phase 1 will consist of setting specific and quantifiable targets for total phosphorus, algal biomass and Secchi depth expressed as Carlson's Trophic State Index (TSI). Phase 2 will consist of implementing the monitoring plan, evaluating collected data, and readjusting target values if needed.

Monitoring is essential to all TMDLs in order to:

- Assess the future beneficial use status;
- Determine if the water quality is improving, degrading or remaining stable;
- Evaluate the effectiveness of implemented best management practices.

The additional data collected will be used to determine if the implemented TMDL and watershed management plan have been or are effective in addressing the identified water quality impairments. The data and information can also be used to determine if the TMDLs have accurately identified the required components (i.e. loading/assimilative capacity, load allocations, in-lake response to pollutant loads, etc.) and if revisions are appropriate.

This TMDL has been prepared in compliance with the current regulations for TMDL development that were promulgated in 1992 as 40 CFR Part 130.7. These regulations and consequent TMDL development are summarized below:

1. **Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:** Silver Lake, S14, T100N, R22W, 8 miles north of the City of Joice, Worth County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutants causing the water quality impairments are algae and turbidity associated with excessive nutrient (phosphorus) loading. Designated uses for Silver Lake are Primary Contact Recreation (Class A1), Aquatic Life (Class B(LW)), and HQR (high quality resource). Excess nutrient loading has impaired aesthetic and aquatic life water quality narrative criteria (567 IAC 61.3(2)) and hindered the designated uses.

3. **Quantification of the pollutant load that may be present in the waterbody and still allow attainment and maintenance of water quality standards:** The Phase 1 target of this TMDL is a Carlson's Trophic State Index (TSI) of less than 70 for total phosphorus, and TSI values of less than 65 for both chlorophyll a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters.

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards:** The existing mean values for Secchi depth, chlorophyll a and total phosphorus based on 2000 - 2004 sampling are 0.4 meters, 59 ug/L and 207 ug/L, respectively. The

estimated existing annual total phosphorus load to Silver Lake is 1,664 pounds per year. The total phosphorus loading capacity for the lake based on lake response modeling is a function of the relative contribution of internal and external loads as shown in Table 2 and as described by the mathematical relationships given in Appendix E.

5. **Identification of pollution source categories:** Nonpoint and atmospheric deposition (background) sources and internal recycling of phosphorus from the lake bottom sediments have been identified as the cause of impairment to Silver Lake.

6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the Silver Lake watershed. Therefore, the wasteload allocation will be set at zero.

7. **Load allocations for pollutants from nonpoint sources:** The total phosphorus load allocation for the nonpoint sources is shown in Table 2. This includes 120 pounds per year attributable to atmospheric deposition.

Table 2. Silver Lake Total Phosphorus Loads

Total Phosphorus Load Allocation/Target Loads (lbs/year)			**Required Load Reduction (lbs/year)**
Internal	**External**	**Total**	
0	1,330	1,330	334
20	1,240	1,260	424
40	1,150	1,190	514
60	1,050	1,110	614
80	960	1,040	704
100	870	970	794
120	770	890	894
140	680	820	984
160	590	750	1,074
180	490	670	1,174
200	400	600	1,264
220	310	530	1,354
240	220	460	1,444
260	120	380	1,544
280	30	310	1,634

8. **A margin of safety:** The target total phosphorus loads are calculated using an in-lake concentration 10% below the desired endpoint to ensure that the required load reduction will result in attainment of water quality targets.

9. **Consideration of seasonal variation:** This TMDL was developed based on the annual phosphorus loading that will result in attainment of TSI targets for the growing season (May through September).

10. **Allowance for reasonably foreseeable increases in pollutant loads:** An allowance for increased sediment and nutrient loading was not included in this TMDL. Significant changes in the Silver Lake watershed landuse are unlikely. Future increases in the rough fish population or intensification of activities that add to lake turbulence could increase re-suspension of settled solids and nutrients. Because such events cannot be predicted or quantified at this time, a future allowance for their potential occurrence was not included in the TMDL.

11. **Implementation plan:** Although not required by the current regulations, an implementation plan is outlined in the report.

2. Silver Lake, Description and History

2.1 The Lake

Silver Lake is a natural, glacial lake located in north central Iowa, 8 miles north of Joice. Public use for Silver Lake is estimated at 3,500 visitors per year. Users of the lake and of Silver Lake enjoy fishing, swimming, boating, picnicking, and camping.

Silver Lake has a maximum depth of 6 feet and a mean depth of 4.5 feet.

Table 3. Silver Lake Features

Waterbody Name:	Silver Lake
Hydrologic Unit Code:	HUC10 0708020202
IDNR Waterbody ID:	IA 02-SHL-00295-L
Location:	Section 14 T100N R22W
Latitude:	43° 29' N
Longitude:	93° 25' W
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW)) 3. High Quality Resource (HQR)
Tributaries:	none
Receiving Waterbody:	Goose Creek to Shellrock River
Lake Surface Area:	334 acres
Maximum Depth:	6 feet
Mean Depth:	4.5 feet
Volume:	1,497 acre-feet
Length of Shoreline:	13,512 feet
Watershed Area:	1,708 acres
Watershed/Lake Area Ratio:	5.1:1
Estimated Detention Time:	1.24 years

Morphometry

Silver Lake has a mean depth of 4.5 feet and a maximum depth of 6 feet. The lake surface area is 316 acres and the storage volume is approximately 1,497 acre-feet. Silver Lake is a shallow lake with a peat bottom. The lake has a brownish coloration due to the constant mixing and recycling, and is contributing to the poor water transparency. Temperature and dissolved oxygen sampling indicate that Silver Lake remains oxic and relatively well mixed throughout the growing season.

Hydrology

Surface water enters Silver Lake through overland runoff and through a small channel from the 109 acre Silver Lake Marsh. Silver Lake Marsh also has no direct tributaries, but receives the majority of the surface runoff prior to draining to Silver Lake. Silver Lake discharges to Goose Creek, a tributary of the Shellrock River. The estimated annual average detention time is 1.24 years based on outflow. The methodology and calculations used to determine the detention time are shown in Appendix A.

2.2 The Watershed

The Silver Lake watershed has an area of approximately 1,536 acres and has a watershed to lake ratio of 5.1:1. The 2005 landuses and associated areas for the watershed were determined from satellite imagery and are shown in Table 4.

Table 4. 2005 Landuse in Silver Lake watershed

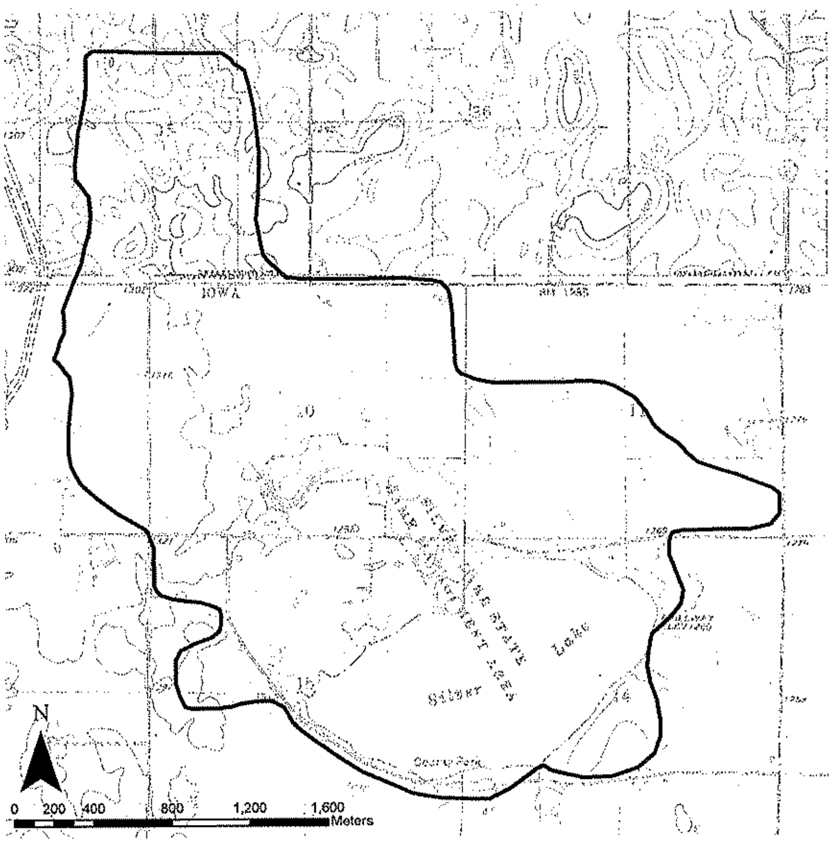
Landuse	**Area in Acres**	**Percent of Total Area**
Row Crop	965	63
Timber	226	15
Grass,CRP,Alfalfa	151	10
Water, Wetlands	81	5
Artificial (roads, farms, etc)	81	5
Parklands, Wildlife Area	32	2
Total	1536	100

The recent field level watershed assessment completed in May 2005 by the Worth County Soil and Water Conservation District determined current landuses and associated cropping practice factors for use in calculating soil loss and delivery.

The watershed is predominately nearly level to moderately sloping (0-9%) prairie-derived soils. Major soils in the watershed include Clarion, Lester, Webster, Okoboji, and Nicollet soils developed from Wisconsin till on the Cary Lobe. A third of the watershed includes very poorly drained depressional soils. Average rainfall in the area is 32.2 inches/year.

Land use maps for both 2002 and 2005 are shown in Appendix D.

Figure 1. Silver Lake Watershed



3. TMDL for Algae and Turbidity

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The Iowa Water Quality Standards (23) list the designated uses for Silver Lake as Primary Contact Recreational Use (Class A1), Aquatic Life (Class B(LW)), and High Quality Resource (HQR). In 1998, Silver Lake was included on the impaired waters list as recommended by the DNR Fisheries and Water Quality bureaus due to problems with algal blooms and organic enrichment. At that time, Class A and B uses were assessed as "partially supported."

In 2002, the Class A designated use was assessed as "partially supporting" and Class B use remained "partially supported" for Silver Lake. This assessment was based upon the 2000-01 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries Bureau.

In 2004, the Class A designated use assessment was downgraded as "not supported" and Class B use remained "partially supported" for Silver Lake. This assessment was based upon the 2000-2002 ISU lake survey, an ISU report on lake phytoplankton, and information from the DNR Fisheries Bureau.

Silver Lake has a history of problems with algal blooms. This condition indicates impairments to the Class A use through presence of aesthetically objectionable blooms of algae and presence of nuisance algal species (e.g., bluegreen algae). ISU sampling in 2000 and 2001 show that bluegreen algae comprise nearly 100% of the wet mass of the phytoplankton community throughout the growing season.

Data Sources

Water quality surveys have been conducted on Silver Lake in 1979, 1990, and 2000-04 (1,2,3,4,5,6,7). Data from these surveys is available in Appendix B.

Iowa State University Lake Study data from 2000 to 2004 were evaluated for this TMDL. This study began in 2000 and ran through 2004 and approximates a sampling scheme used by Roger Bachmann in earlier Iowa lake studies. Samples were collected three times during the early, middle and late summer. A number of water quality parameters were measured including Secchi disk depth, phosphorus series, nitrogen series, TSS, and VSS.

Interpreting Silver Lake Water Quality Data

Based on mean values from ISU sampling during 2000 - 2004, the ratio of total nitrogen to total phosphorus for this lake is 12:1; suggesting that algal production at this lake is potentially limited by nitrogen availability. Data on inorganic suspended solids from the ISU survey indicate that this lake is subject to high levels of non-algal turbidity that may limit algal production. The mean level of inorganic suspended solids in the 131 lakes sampled for the ISU lake survey in 2000 through 2004 was 5.3 mg/l. The mean level of inorganic suspended solids at Silver Lake during the same time period was 14.4 mg/l, thus suggesting that non-algal turbidity limits the production of algae as well as contributes to turbidity and reductions in water transparency. The lake does not have a population of common carp but does have significant numbers of bullheads. Much of the suspended inorganic material in the water column of Silver Lake is due primarily to suspended algae and secondarily to re-suspend inorganic material.

Data from ISU phytoplankton sampling in 2000 through 2002 indicate that bluegreen algae (Cyanophyta) completely dominate the summertime phytoplankton community of Silver Lake (22,25). The number of available samples (three per summer) is insufficient to fully characterize the frequency of algal blooms. However, the sampling does indicate an extremely high level of bluegreen mass relative to other Iowa lakes. The 2000 average summer wet mass of bluegreen algae at this lake (463 mg/l) is the third highest of 131 lakes sampled. The 2000 through 2004 phytoplankton sampling results are given in Appendix B.

Comparisons of the TSI values for chlorophyll, Secchi depth and total phosphorus for in-lake sampling reaffirm that despite very high chlorophyll levels, a non-phosphorus limitation to algal growth is present (see Figure 2 and Appendix C). This non-phosphorus limitation is attributable to light attenuation by elevated levels of inorganic suspended solids. Since the phytoplankton community at Silver Lake is comprised primarily of bluegreen algae, it is less likely that the low nitrogen to phosphorus ratio is currently limiting algal growth.

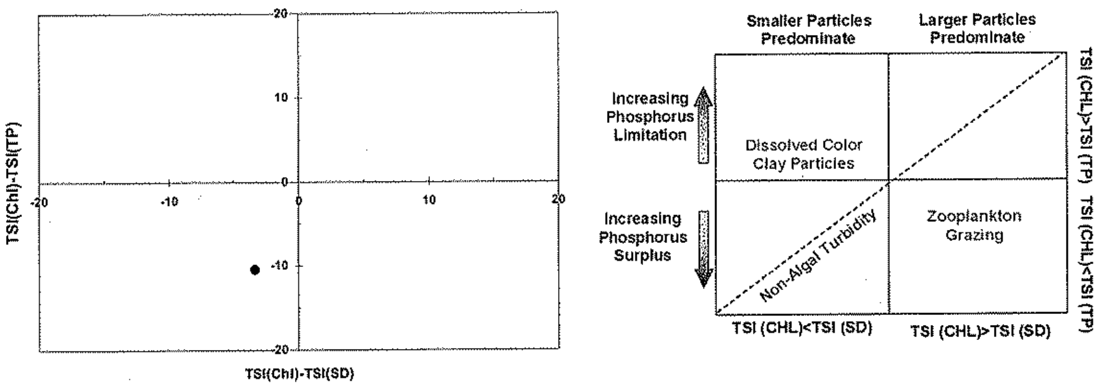
Based on the nitrogen to phosphorus ratio, nitrogen is currently the limiting nutrient at Silver Lake, presumably due to the overabundance of phosphorus. However, a reduction in nitrogen levels is unlikely to significantly curtail nuisance blooms of bluegreen algae due to their ability to fix atmospheric nitrogen. Therefore, phosphorus is the targeted nutrient in this TMDL.

TSI values for 2000 - 2004 monitoring data are shown in Table 5. TSI values for all historical monitoring data and an explanation of Carlson's Trophic State Index are given in Appendix C.

Table 5. Silver Lake TSI Values (3,4,5,6,7)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/05/2000	73	74	90
7/31/2000	77	72	88
9/06/2000	93	70	88
6/05/2001	60	57	69
7/10/2001	77		79
8/06/2001	73	69	71
6/11/2002	83	75	86
7/16/2002	77	71	74
8/12/2002	77	67	79
6/10/2003	59	49	81
7/15/2003	73	57	79
8/12/2003	83	66	77
6/8/2004	77	77	82
7/13/2004	83	69	76
8/9/2004	83	79	80

Figure 2. Silver Lake 2000 - 2004 Mean TSI Multivariate Comparison Plot (21)



Potential Pollution Sources

Water quality in Silver Lake is influenced only by watershed nonpoint sources and internal recycling of pollutants from bottom sediments. There are no point source discharges in the watershed.

As stated previously, the lake does not have a population of common carp but does have significant number of bullheads. Thus, the water quality conditions at Silver Lake indicate excessive nutrient and sediment loading to the water column, nuisance blooms of algae, organic enrichment and re-suspension of sediment from the watershed and internal recycling due to wind and wave action.

Silver Lake is used by migratory waterfowl, but does not have a large resident population that can be sporadically contributing nutrient loads to the lake.

Natural Background Conditions

For the phosphorus load attributable to atmospheric deposition directly on the lake surface, the annual average concentration of phosphorus in precipitation was assumed to be 0.05 mg/L based on a review of available literature (11,17,18,19) and the default values used in the EUTROMOD and WILMS modeling programs. Contributions of phosphorus attributable to dry atmospheric deposition were not separated from the direct precipitation load. Potential phosphorus contributions from groundwater influx were not separated from the total nonpoint source load.

3.2 TMDL Target

The Phase 1 target of this TMDL is a TSI of less than 70 for total phosphorus, and TSI values of less than 65 for both chlorophyll a and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters.

Table 6. Silver Lake Existing vs. Target TSI Values

Parameter	2000-2004 Mean TSI	2000-2004 Mean Value	Target TSI	Target Value	Minimum In-Lake Increase or Reduction Required
Chlorophyll	68	59 ug/L	<65	<33 ug/L	44% Reduction
Secchi Depth	77	0.4 meters	<65	>0.7 meters	75% Increase in transparency
Total Phosphorus	80	207 ug/L	<70	<96 ug/L	54% Reduction

A second target is the attainment of aquatic life uses as measured by fishery and biological assessments. The aquatic life target for this TMDL will be achieved when the fishery of Silver Lake is determined to be fully supporting the aquatic life uses. This determination will be accomplished through an assessment conducted by the IDNR Fisheries Bureau.

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for algae or turbidity. The algae and turbidity impairments are due to algal blooms caused by excessive nutrient loading to the lake and resuspension of inorganic suspended solids. The nutrient loading objective is defined by a mean total phosphorus TSI of less than 70, which is related through the Trophic State Index to chlorophyll and Secchi depth. The TSI is not a standard, but is used as a guideline to relate phosphorus loading to the algal impairment for TMDL development purposes and to describe water quality that will meet Iowa's narrative water quality standards.

Selection of Environmental Conditions

The critical condition for which the TMDL TSI target values apply is the growing season (May through September). It is during this period that nuisance algal blooms are prevalent. The existing and target total phosphorus loadings to the lake are expressed as annual averages. Growing season mean (GSM) in-lake total phosphorus concentrations are used to calculate an annual average total phosphorus loading.

Modeling Approach

A number of different empirical models that predict annual phosphorus load based on measured in-lake phosphorus concentrations were evaluated. In addition, watershed phosphorus delivery using both export coefficients and an annual loading function model as outlined in Reckhow's EUTROMOD User's Manual (24) was calculated. The results from both approaches were compared to select the best-fit empirical model.

Table 7. Model Results

Model	Predicted Existing Annual Total Phosphorus Load (lbs/yr) for in-lake GSM TP = ANN TP = 207 ug/L,	Comments
Loading Function	1,664	Reckhow (10)
EPA Export	1,826	EPA/5-80-011
WILMS Export	1,225	"most likely" export coefficients
Reckhow 1991 EUTROMOD Equation	354,231	GSM model
Canfield-Bachmann 1981 Natural Lake	3,805	GSM model
Canfield-Bachmann 1981 Artificial Lake	10,448	GSM model
Reckhow 1977 Anoxic Lake	911	GSM Model
Reckhow 1979 Natural Lake	7,962	GSM Model.
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	2,055	GSM model. P/Pin out of range
Nurnberg 1984 Oxic Lake	1,101 (internal load = 443)	Annual model.
Walker Resevoir	5,198	SPO model.
Vollenweider 1982 Combined OECD	2,711	Annual model.
Vollenweider 1982 Shallow Lake	2,904	Annual model

The Reckhow Anoxic, Reckhow Oxic, Walker, Nurnberg and Vollenweider models resulted in values closest to the Loading Function and export estimates. Of these, only the Reckhow Anoxic and Walker models are within the parameter ranges used to derive them when applied to Silver Lake with its extremely high in-lake phosphorus levels. Silver Lake is an oxic lake, making application of the Reckhow Anoxic Model questionable. The Walker Model is a Spring Overturn (SPO) model. The available in-lake phosphorus monitoring for Silver Lake corresponds with the growing season, requiring late spring or early summer sampling values to be used as a surrogate for the early spring phosphorus values used to derive the Walker Model.

The Reckhow Oxic and Vollenweider models return values that are above, but reasonably close to, the range predicted by the Loading Function and export estimates. However, the high phosphorus and inorganic suspended solids levels at Silver Lake indicate the likelihood of a significant internal loading. The existing load predicted by the Nurnberg Model also indicates a significant internal load. Therefore, use of the Loading Function estimate with the Nurnberg Oxic Lake Model was selected as the basis for determining the existing load. The Nurnberg Model was also used to determine load targets as a function of the relative contribution from internal and external sources.

The equation for the Nurnberg Oxic Lake Model is:

$$P = \frac{L_{Ext}}{q_s}(1 - R) + \frac{L_{Int}}{q_s}$$

where

$$R = \frac{15}{18 + q_s}$$

P = predicted in-lake total phosphorus concentration (ug/L)
L_{Ext} = external areal total phosphorus load (mg/m^2 of lake area per year)
L_{Int} = internal areal total phosphorus load (mg/m^2 of lake area per year)
q_s = areal water loading (m/yr)
The Nurnberg Model represents a possible continuum of internal and external loads for a given in-lake total phosphorus concentration. The Loading Function Model external load estimate was used in combination with the Nurnberg Model to determine the existing loads as follows:

$$P = 207(\mu g / L) = \frac{369(mg / m^2)}{1.10(m / yr)}(1 - \frac{15}{18 + 1.10(m / yr)}) + \frac{149(mg / m^2)}{1.10(m / yr)}$$

An example of a load calculation for target internal and external loads of 100 and 870 pounds, respectively, is:

$$P = 87(\mu g / L) = \frac{292(mg / m^2)}{1.10(m / yr)}(1 - \frac{15}{18 + 1.10(m / yr)}) + \frac{33.6(mg / m^2)}{1.10(m / yr)}$$

The above calculation includes a margin of safety by using an in-lake concentration 10% below the desired endpoint (P < 96 ug/L) to calculate the target loads. The annual total phosphorus loads are obtained by multiplying the areal loads (L_{Ext}, L_{Int}) by the lake area in square meters and converting the resulting values from milligrams to pounds.

For the in-lake total phosphorus target and any selected target internal load, the corresponding target external load, target total load or target load reduction can be calculated from the relationships shown in Figure E-1 in Appendix E.

Waterbody Pollutant Loading Capacity

The chlorophyll a and Secchi depth objectives are related through the Trophic State Index to total phosphorus. The load capacity for this TMDL is the annual amount of phosphorus Silver Lake can receive and meet its designated uses. The Phase 1 target

TSI (TP) value is less than 70, corresponding with an in-lake total phosphorus concentration of less than 96 ug/L. For the selected lake response model, the target total load is a function of the relative internal and external load contributions as shown in Table 8.

Table 8. Silver Lake Total Phosphorus Target

Total Phosphorus Target Loads (lbs/year)		
Internal	**External**	**Total**
0	1,330	1,330
20	1,240	1,260
40	1,150	1,190
60	1,050	1,110
80	960	1,040
100	870	970
120	770	890
140	680	820
160	590	750
180	490	670
200	400	600
220	310	530
240	220	460
260	120	380
280	30	310

3.3 Pollution Source Assessment

There are three quantified phosphorus sources for Silver Lake in this TMDL. The first is the phosphorus load from the watershed that drains directly into the lake. The second source is internal phosphorus loading from re-suspended sediments. The third source is atmospheric deposition. Note that load contributions from groundwater influx have not been separated from the total nonpoint source loads.

Existing Load

The annual total phosphorus load to Silver Lake is estimated to be 1,644 pounds per year based on the Loading Function and Nurnberg Oxic Lake models. This estimate includes 1,101 pounds per year from external nonpoint sources in the watershed, 443 pounds per year attributable to internal loading, and 120 pounds per year from atmospheric deposition.

Departure from Load Capacity

Table 9 shows the load reductions necessary to achieve and maintain Phase 1 water quality goals.

Table 9. Silver Lake Load Reductions to Meet Phase 1 Goals

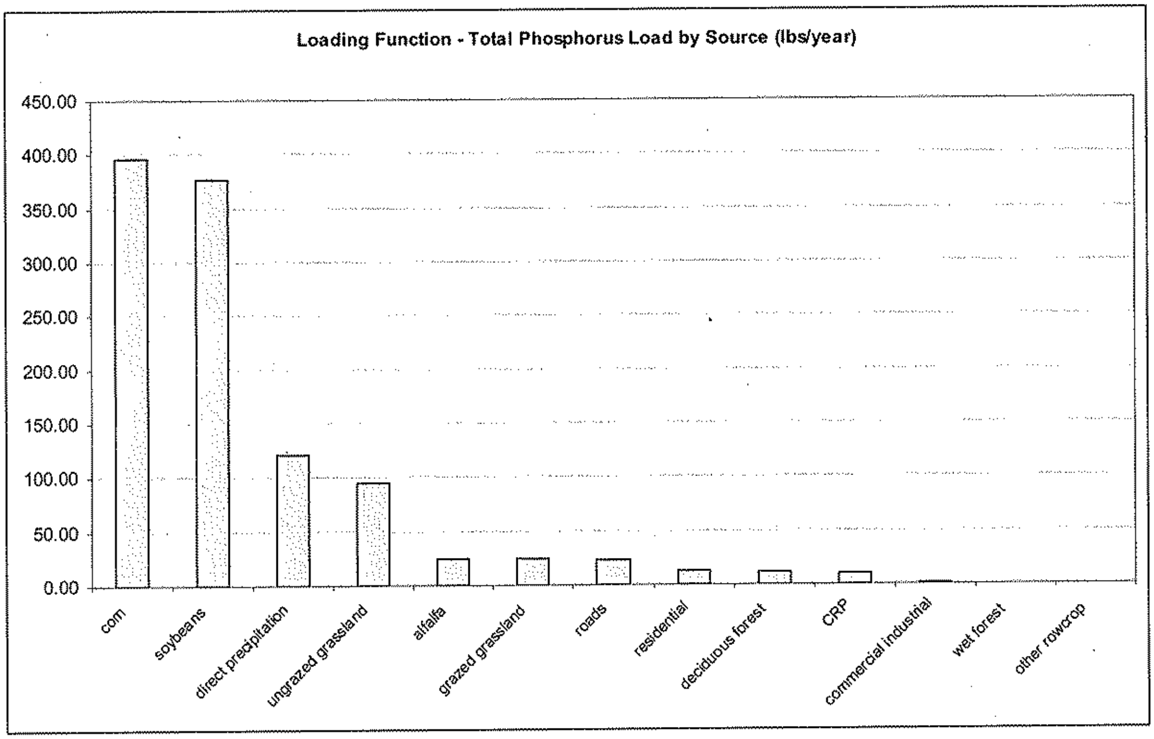
Total Phosphorus Loads (lbs/year)		Required Load Reduction (lbs/year)
Internal	External	
0	1,330	334
20	1,240	424
40	1,150	514
60	1,050	614
80	960	704
100	870	794
120	770	894
140	680	984
160	590	1,074
180	490	1,174
200	400	1,264
220	310	1,354
240	220	1,444
260	120	1,544
280	30	1,634

Identification of Pollutant Sources

There are no significant point source discharges in the Silver Lake watershed. From the Loading Function Model, the most external nonpoint source phosphorus delivered to the lake is from row crop landuse as shown in Figure 3. It should be noted that while the Loading Function Model provides estimates of the primary potential pollutant sources and a means of estimating existing internal versus external loads, the existing and target total loads identified in this TMDL are independent of the Loading Function Model. The Loading Function Model was used only for comparison purposes to select an empirical lake response model and to separate the existing total load predicted by the lake response model into internal and external components. Existing and target loads were calculated from measured and target in-lake total phosphorus concentrations using the selected lake response model as shown in *Section 3.2, Modeling Approach*. Also, the Loading Function Model estimates only external watershed phosphorus inputs and does not account for internal loading.

The Nurnberg Model indicates that internal loading makes up approximately 29% of the existing total phosphorus mass loading to the lake. However, the internal load has a much greater effect on in-lake total phosphorus concentrations on a pound for pound basis. The model relationship shows that one pound of internal loading is equivalent to 4.7 pounds of external loading. In terms of lake response, the internal load is estimated to comprise approximately 65% of the total load.

Figure 3. Loading Function Model External Nonpoint Source Contributions



Other sources of phosphorus capable of being delivered to the water body exist. These sources include septic systems and toilet pits from campsites, individual residences, and seasonal-use businesses and housing units. Manure and waste from wildlife, pets, fish cleaning stations, and etc. also contribute to the phosphorus loading. Unfortunately, the potential phosphorus being contributed from these sources is difficult to quantify. These potential sources have been considered, but are deemed smaller contributors or have less impact than the sources previously identified. However, these sources will be evaluated and quantified as required in Phase II of this TMDL.

Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Silver Lake originates entirely from nonpoint sources and internal recycling. To meet the TMDL endpoint, the annual nonpoint source and internal recycling contributions to Silver Lake must be reduced as shown in Table 9 (above).

3.4 Pollutant Allocation

Wasteload Allocation

Since there are no significant phosphorus point source contributors in the Silver Lake watershed, the Waste Load Allocation (WLA) is zero pounds per year.

Load Allocation

Table 10 shows the Load Allocation (LA) for this TMDL based on varying internal and external load contributions. The external and total loads include 120 pounds per year from atmospheric deposition.

Table 10. Silver Lake Load Allocation

Total Phosphorus Load Allocation (lbs/year)		
Internal	**External**	**Total**
0	1,330	1,330
20	1,240	1,260
40	1,150	1,190
60	1,050	1,110
80	960	1,040
100	870	970
120	770	890
140	680	820
160	590	750
180	490	670
200	400	600
220	310	530
240	220	460
260	120	380
280	30	310

Margin of Safety

The target established for Silver Lake is a total phosphorus concentration of 96 ug/L. To account the margin of safety, a concentration of 87 ug/L was used in the calculations. The target total phosphorus loads are calculated using an in-lake concentration 10% below the desired endpoint to account for uncertainties in the analysis and to ensure that the required load reduction will result in attainment of water quality targets.

4. Implementation Plan

The following implementation plan is not a required component of a Total Maximum Daily Load but can provide department staff, partners, and watershed stakeholders with a strategy for improving Silver Lake water quality.

Silver Lake receives nutrient loading from the watershed and through internal recycling. This results in high levels of chlorophyll-a and the related algal blooms and secondarily to high levels of inorganic turbidity.

Turbulent sediment re-suspension and internal recycling.
A large fraction of the TP load in Silver Lake results from recycling of previously settled phosphorous. This phosphorous is entrained with sediment that is disturbed by wind action and motorboats. Suggested controls are:

- Reduce turbulence from motorboats and other water craft

- Minimize wind impacts with wind breaks.

A marsh located on the northwest side of the lake at one time acted as a filter. The filtration process removes much of the water's nutrient and pollutant load, which in turn improves the water quality in the lake. The marsh has since filled in with silt, and the water has found a new path in to the lake. An assessment of the wetland should be done to see if restoration (possibly dredging) is necessary to increase the volume and efficiency of the marsh to help protect water quality.

The 2005 watershed assessment identified current landuses and best management practices. Although the watershed is a secondary contributor to water quality at Silver Lake, best management practices should continue to be promoted and maintained in the watershed.

5. Monitoring

Further monitoring is needed at Silver Lake to follow-up on the implementation of the TMDL. This monitoring will, at a minimum, meet the minimum data requirements established by Iowa's 305(b) guidelines for a complete water quality assessment (3 lake samples per year over 3 years, 10 lake samples over 2 years, etc.). This data will be collected by 2010. Silver Lake was included in the five-year lake study conducted by Iowa State University under contract with the IDNR. Although this lake monitoring program concluded in 2004, other programs are continuing.

Worth County Conservation Board is working with the Water Monitoring Section of the DNR continue monitoring at seven locations in the watershed and in the lake through 2006.

The phosphorus load due to internal recycling is estimated by the selected lake response model but due to uncertainty inherent in the available data and model predictions further investigation is warranted. The department is working with Iowa State University to develop a method for quantifying phosphorus sediment flux that will clarify its impact on lakes. When a protocol for measuring phosphorus flux becomes available, coring will be done for this lake and the recycling load component estimate will be further refined.

6. Public Participation

DNR staff met with local stakeholders at the USDA Service Center Building in Northwood on June 2, 2005 to discuss the water quality in Silver Lake and to discuss the TMDL process. The draft TMDL was presented at a public meeting in Northwood, Iowa on January 10, 2006. The public addressed their concerns to maintain the current uses of the lake, including fishing, boating, and primary contact recreation. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

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8. Appendix A - Lake Hydrology

Application to Silver Lake – Calculations (20)

Table A-5. Silver Lake Hydrology Calculations

Lake	Silver Lake (Worth County)	
Type	Natural	
Inlet(s)	none	
Outlet(s)	DD64	
Volume	1497	acre-feet
Surface Area	334	acres
Watershed Area	2043	acres
Mean Annual Precipitation	32.2	inches
Average Basin Slope	1.8	%
% Forest (2000 Land Cover)	7.9	
% Corn (2000 Land Cover)	27.4	
% Rowcrop (2002 Land Cover)	57.2	
Basin Soils Average % Sand	21.0	
Soil Permeability	0.8	inches/hour
Mean Annual Class A Pan Evaporation	45	inches
Evaporation Coefficient	0.74	
Mean Depth	4.5	feet
Drainage Area	1708	acres
Drainage Area	2.7	square miles
Drainage Area/Lake Area	5.1	
Mean Annual Lake Evaporation	33.3	inches
Mean Annual Lake Evaporation	927	acre-feet/year
Annual Average Inflow	1.7	cfs
Annual Average Inflow	1240	acre-feet/year
Runoff Component	1001	acre-feet/year
Baseflow Component	240	acre-feet/year
Direct Precipitation on Lake Surface	897	acre-feet/year
Inflow + Direct Precipitation	2137	acre-feet/year
% Inflow	58.0	
% Direct Precipitation	42.0	
Outflow	1210	acre-feet/year
HRT Based on Inflow + Direct Precipitation	0.70	year
HRT Based on Outflow	1.24	year

9. Appendix B - Sampling Data

Table B-1. Data collected in 1979 by Iowa State University (1)

Parameter	7/26/1979	8/23/1979	9/25/1979
Secchi Depth (m)	0.7	0.3	0.5
Chlorophyll (ug/L)	145.9	92.4	24.8
NO_3+NO_2-N (mg/L)			0.08
Total Phosphorus (ug/l as P)	520	440	190
Alkalinity (mg/L)	132	110	120

Data above is averaged over the upper 6 feet.

Table B-2. Data collected in 1990 by Iowa State University (2)

Parameter	5/27/1990	6/28/1990	7/26/1990
Secchi Depth (m)	0.4	0.5	0.8
Chlorophyll (ug/L)	34	11.2	17.9
Total Nitrogen (mg/L as N)	3.0	5.3	2.4
Total Phosphorus (ug/l as P)	203.1	151.7	88.1
Total Suspended Solids (mg/L)	15.6	17.8	12.7
Inorganic Suspended Solids (mg/L)	0	2.9	6.8

Data above is for surface depth.

Table B-3. Data collected in 2000 by Iowa State University (3)

Parameter	7/05/2000	7/31/2000	9/06/2000
Secchi Depth (m)	0.4	0.3	0.1
Chlorophyll (ug/L)	83.7	66.4	56.8
NH_3+NH_4^+ -N (ug/L)			
NH_3 –N (un-ionized) (ug/L)			
NO_3+NO_2-N (mg/L)	0.3	0.24	0.34
Total Nitrogen (mg/L as N)	2.1	2.84	1.73
Total Phosphorus (ug/l as P)	384	345	325
Silica (mg/L as SiO_2)			
pH	6.8	9.1	9.4
Alkalinity (mg/L)	143	125	99
Total Suspended Solids (mg/L)	47	36	110
Inorganic Suspended Solids (mg/L)	10	17	26
Volatile Suspended Solids (mg/L)	37	19	84

Table B-4. Data collected in 2001 by Iowa State University (4)

Parameter	6/05/2001	7/10/2001	8/06/2001
Secchi Depth (m)	1	0.3	0.4
Chlorophyll (ug/L)	14.7		50.8
NH_3+NH_4^+ -N (ug/L)			
NH_3 –N (un-ionized) (ug/L)			
NO_3+NO_2-N (mg/L)	0.12	0.11	0.29
Total Nitrogen (mg/L as N)	1.81	1.32	1.55
Total Phosphorus (ug/l as P)	87	174	101
Silica (mg/L as SiO_2)			
pH	8.4	10	9.6
Alkalinity (mg/L)	104	96	90
Total Suspended Solids (mg/L)	23	29	50
Inorganic Suspended Solids (mg/L)	7	18	
Volatile Suspended Solids (mg/L)	16	11	

Table B-5. Data collected in 2002 by Iowa State University (5)

Parameter	6/11/2002	7/16/2002	8/12/2002
Secchi Depth (m)	0.2	0.3	0.3
Chlorophyll (ug/L)	89.9	60.2	41.9
NH_3+NH_4^+ -N (ug/L)	976	636	373
NH_3 –N (un-ionized) (ug/L)	386	83	202
NO_3+NO_2-N (mg/L)	0.24	0.25	0.25
Total Nitrogen (mg/L as N)	1.88	2.08	
Total Phosphorus (ug/l as P)	292	125	175
Silica (mg/L as SiO_2)	3.63	8.88	9.65
pH	9.1	8.4	9.3
Alkalinity (mg/L)	130	125	105
Total Suspended Solids (mg/L)	18	10	60
Inorganic Suspended Solids (mg/L)	7		10
Volatile Suspended Solids (mg/L)	11		50

Table B-6. Data collected in 2003 by Iowa State University (6)

Parameter	6/10/2003	7/15/2003	8/12/2003
Secchi Depth (m)	1.1	0.4	0.2
Chlorophyll (ug/L)	6.7	14.4	38.6
NH_3+NH_4^+ -N (ug/L)	2433	981	432
NH_3 –N (un-ionized) (ug/L)	91	107	156
NO_3+NO_2-N (mg/L)	0.84	0.23	0.19
Total Nitrogen (mg/L as N)	4.62	3.09	3.02
Total Phosphorus (ug/l as P)	202	175	157
Silica (mg/L as SiO_2)	2.97	4.69	5.77
pH	8	8.4	9
Alkalinity (mg/L)	120	97	83
Total Suspended Solids (mg/L)	17	47	41
Inorganic Suspended Solids (mg/L)	10	19	11
Volatile Suspended Solids (mg/L)	7	27	30

Table B-7. Data collected in 2004 by Iowa State University (7)

Parameter	6/08/2003	7/13/2003	8/09/2003
Secchi Depth (m)	0.3	0.2	0.2
Chlorophyll (ug/L)	111.9	51.9	140.6
NH_3+NH_4^+ -N (ug/L)	799	503	657
NH_3 –N (un-ionized) (ug/L)	253	190	551
NO_3+NO_2-N (mg/L)	0.43	0.11	0.39
Total Nitrogen (mg/L as N)	3.44	1.57	2.31
Total Phosphorus (ug/l as P)	221	143	193
Silica (mg/L as SiO_2)	3.49	4.94	11.14
pH	9	9	10
Alkalinity (mg/L)	117	105	98
Total Suspended Solids (mg/L)	48	44	52
Inorganic Suspended Solids (mg/L)	20	18	
Volatile Suspended Solids (mg/L)	28	26	52

Table B-8. 2000 Phytoplankton Data (22)

	7/05/2000	7/31/2000	9/06/2000
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	5.55E+00	6.18E-01	9.30E-02
Chlorophyta	3.26E+00	3.87E+01	5.60E-02
Cryptophyta	3.77E-01	1.28E+00	1.25E-01
Cyanobacteria	3.26E+02	1.69E+02	8.70E+02
Dinophyta	1.63E-01	2.16E+00	0.00E+00
Euglenophyta	4.90E-02	3.97E+00	0.00E+00
Total	3.36E+02	2.16E+02	8.70E+02

Table B-9. 2001 Phytoplankton Data (25)

	6/05/2001	7/10/2001	9/06/2001
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	0.00E+00	7.54E+00	1.75E+00
Chlorophyta	0.00E+00	8.90E-02	3.58E-01
Cryptophyta	2.93E-01	0.00E+00	0.00E+00
Cyanobacteria	1.52E+00	2.26E+02	2.48E+02
Dinophyta	0.00E+00	0.00E+00	0.00E+00
Euglenophyta	0.00E+00	0.00E+00	0.00E+00
Total	1.82E+00	2.34E+02	2.50E+02

Table B-10. 2002 Phytoplankton Data (26)

	6/11/2002	7/16/2002	8/12/2002
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	1.31E+00	1.33E+00	3.78E-01
Chlorophyta	3.49E+00	1.26E+00	0.00E+00
Cryptophyta	7.70E-02	2.40E-02	3.06E-01
Cyanobacteria	3.04E+02	2.56E+02	7.88E+00
Dinophyta	0.00E+00	5.99E+00	0.00E+00
Euglenophyta	0.00E+00	0.00E+00	0.00E+00
Total	3.09E+02	2.65E+02	8.56E+00

Table B-11. 2003 Phytoplankton Data (27)

	6/10/2003	7/15/2003	8/12/2003
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	6.65E-01	2.35E+00	2.81E+00
Chlorophyta	5.66E-01	3.68E+00	3.53E-01
Cryptophyta	4.62E-01	4.93E-01	2.38E-01
Cyanobacteria	2.39E+01	6.46E+02	3.89E+03
Dinophyta	0.00E+00	2.19E-01	0.00E+00
Euglenophyta	0.00E+00	0.00E+00	1.60E-02
Total	2.56E+01	6.53E+02	3.89E+03

Table B-12. 2004 Phytoplankton Data (28)

	6/08/2004	7/13/2004	8/09/2004
Division	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**	**Wet Mass (mg/L)**
Bacillariophyta	1.80E+01	2.44E-01	2.03E+00
Chlorophyta	1.94E+00	9.90E-02	5.50E-02
Cryptophyta	9.63E-01	2.10E-02	2.02E-01
Cyanobacteria	7.48E+02	1.50E+02	2.50E+02
Dinophyta	0.00E+00	1.46E-01	0.00E+00
Euglenophyta	2.09E-01	1.00E-02	0.00E+00
Total	7.69E+02	1.51E+02	2.53E+02

Additional lake sampling results and information can be viewed at:
http://limnology.eeob.iastate.edu/

10. Appendix C - Trophic State Index

Carlson's Trophic State Index

Carlson's Trophic State Index is a numeric indicator of the continuum of the biomass of suspended algae in lakes and thus reflects a lake's nutrient condition and water transparency. The level of plant biomass is estimated by calculating the TSI value for chlorophyll-a. TSI values for total phosphorus and Secchi depth serve as surrogate measures of the TSI value for chlorophyll.

The TSI equations for total phosphorus, chlorophyll and Secchi depth are:

$$TSI\ (TP) = 14.42\ \ln(TP) + 4.15$$

$$TSI\ (CHL) = 9.81\ \ln(CHL) + 30.6$$

$$TSI\ (SD) = 60 - 14.41\ \ln(SD)$$

TP = in-lake total phosphorus concentration, ug/L

CHL = in-lake chlorophyll-a concentration, ug/L

SD = lake Secchi depth, meters

The three index variables are related by linear regression models and *should* produce the same index value for a given combination of variable values. Therefore, any of the three variables can theoretically be used to classify a waterbody.

Table C-1. Changes in temperate lake attributes according to trophic state (modified from U.S. EPA 2000, Carlson and Simpson 1995, and Oglesby et al. 1987).

TSI Value	Attributes	Primary Contact Recreation	Aquatic Life (Fisheries)
50-60	eutrophy: anoxic hypolimnia; macrophyte problems possible	[none]	warm water fisheries only; percid fishery; bass may be dominant
60-70	blue green algae dominate; algal scums and macrophyte problems occur	weeds, algal scums, and low transparency discourage swimming and boating	Centrarchid fishery
70-80	hyper-eutrophy (light limited). Dense algae and macrophytes	weeds, algal scums, and low transparency discourage swimming and boating	Cyprinid fishery (e.g., common carp and other rough fish)
>80	algal scums; few macrophytes	algal scums, and low transparency discourage swimming and boating	rough fish dominate; summer fish kills possible

Table C-2. Summary of ranges of TSI values and measurements for chlorophyll-a and Secchi depth used to define Section 305(b) use support categories for the 2004 reporting cycle.

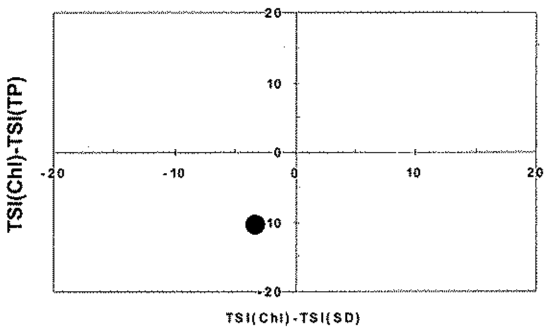
Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates for Section 303(d) listing)	65-70	*33 ➔ 55*	*0.7➔ 0. 5*
not supported (monitored or evaluated: candidates for Section 303(d) listing)	>70	*>55*	*<0.5*

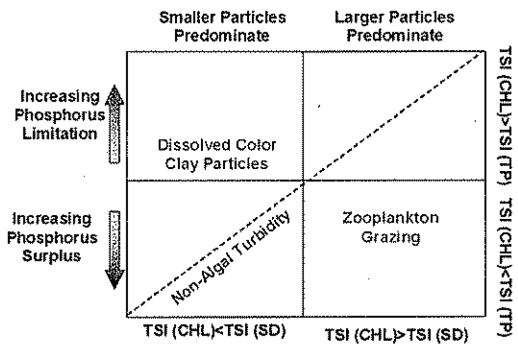
Table C-3. Descriptions of TSI ranges for Secchi depth, phosphorus, and chlorophyll-a for Iowa lakes.

TSI value	Secchi description	Secchi depth (m)	Phosphorus & Chlorophyll-a description	Phosphorus levels (ug/l)	Chlorophyll-a levels (ug/l)
> 75	extremely poor	< 0.35	extremely high	> 136	> 92
70-75	very poor	0.5 – 0.35	very high	96 - 136	55 – 92
65-70	poor	0.71 – 0.5	high	68 – 96	33 – 55
60-65	moderately poor	1.0 – 0.71	moderately high	48 – 68	20 – 33
55-60	relatively good	1.41 – 1.0	relatively low	34 – 48	12 – 20
50-55	very good	2.0 – 1.41	low	24 – 34	7 – 12
< 50	exceptional	> 2.0	extremely low	< 24	< 7

The relationship between TSI variables can be used to identify potential causal relationships. For example, TSI values for chlorophyll that are consistently well below those for total phosphorus suggest that something other than phosphorus limits algal growth. The TSI values can be plotted to show potential relationships as shown in Figure C-1.

Figure C-1. Multivariate TSI Comparison Chart (Carlson)





Silver Lake TSI Values

Table C-4. 1979 Silver Lake TSI Values (1)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/26/1979	65	80	94
8/23/1979	77	75	92
9/25/1979	70	62	80

Table C-5. 1990 Silver TSI Values (2)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
5/27/1990	73	65	81
6/28/1990	70	54	77
7/26/1990	63	59	69

Table C-6. 2000 - 2004 Silver TSI Values (3,4,5,6,7)

Sample Date	TSI (SD)	TSI (CHL)	TSI (TP)
7/05/2000	73	74	90
7/31/2000	77	72	88
9/06/2000	93	70	88
6/05/2001	60	57	69
7/10/2001	77		79
8/06/2001	73	69	71
6/11/2002	83	75	86
7/16/2002	77	71	74
8/12/2002	77	67	79
6/10/2003	59	49	81
7/15/2003	73	57	79
8/12/2003	83	66	77
6/08/2004	77	77	82
7/13/2004	83	69	76
8/09/2004	83	79	80

11. Appendix D - Land Use Maps

Figure D-1. Silver Lake Watershed 2002 Landuse

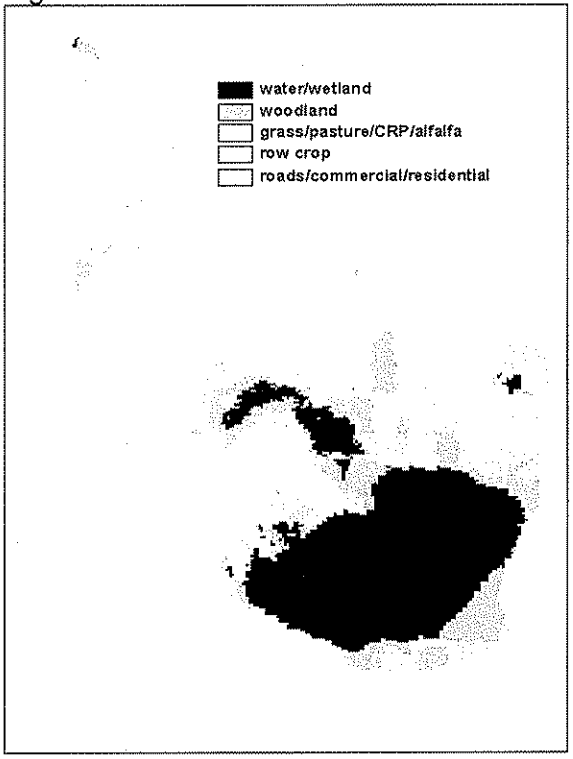
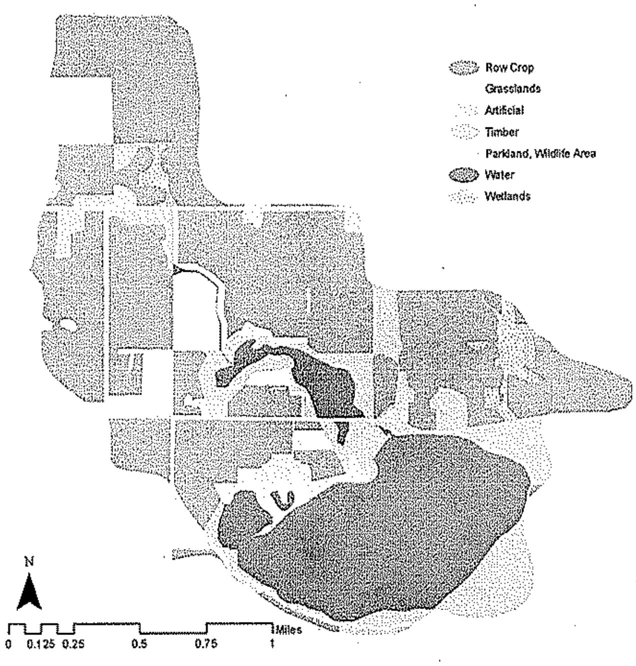


Figure D-2. Silver Lake 2005 Watershed Assessment



12. Appendix E - Silver Lake Loading Relationships

Figure E-1. Silver Lake Target Internal vs. External Load